Haystack Observatory Technology Development Center

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Abstract

Work at the MIT Haystack Observatory is currently focusing on three areas of technology development:

- Mark 5C/DBE2 VLBI data system
- VLBI2010 prototype antenna systems
- e-VLBI

Considerable progress has been made in each of these areas.

1. Mark 5C VLBI Data System

The Mark 5C is being designed as the next-generation Mark 5 high rate data recording system. It will have the capability of recording at sustained rates up to 4096 Mbps. An important feature is that the same disk modules will be used as for the Mark 5A and Mark 5B, thus preserving the existing investments in storage media.

The Mark 5C data interface for both recording and playback will be 10 Gigabit Ethernet, which is rapidly becoming a widely supported standard. Changing from the hardware-defined VSI-H linkage for the Mark 5B to the network-based interface for the Mark 5C offers both advantages and limitations. For example, data playback through the 10GigE interface is expected to be the natural interface to the large-scale software correlators coming into use. On the other hand, implementing the 10GigE interface requires that the data source must be designed to encapsulate data streams in a format compatible with the Mark 5C requirements. However, in the interest of backward compatibility, the Mark 5C will also support writing the disk modules in Mark 5B format to enable correlation on the existing Mark 4 hardware correlators, although only at 2048 Mbps.

Other characteristics of the Mark 5C include the following.

- The standard Mark 5C is fundamentally a dumb Ethernet packet recorder and is independent of the VLBI data format. We plan to use the VLBI Data Interchange Format (VDIF) as soon as that specification becomes available, and we are designing digital backend equipment which will supply data in the VDIF format.
- The Mark 5C will use the same Amazon StreamStor disk-interface card as the Mark 5B+, but the FPDP I/O daughterboard will be replaced with a 10GigE interface card newly designed (by Conduant Corporation). Unlike Mark 5A/B/B+, no separate, specialized I/O card is needed.
- At data rates above about 2 Gbps, it will be necessary to record simultaneously to two 8-disk modules in so-called 'non-bank' mode, which is not normally used by Mark 5A or Mark 5B/B+.

The first prototype Mark 5C systems are expected to be available in mid-2009. Additional information about the Mark 5C systems is available in the Mark 5 memo series at *http://www.haystack.edu/tech/vlbi/mark5/memo.html*, particularly memos 57, 58, 61, and 62.

2. Digital Back Ends

Haystack has been using the first-generation digital backend system, dubbed DBE1, very successfully for almost two years. A second-generation system, dubbed DBE2, is being developed at Haystack based on a newer signal processing board, called ROACH (Reconfigurable Open Architecture Computing Hardware). The ROACH board is the product of a consortium consisting of the UC Berkeley CASPER group, NRAO, and the Karoo Array Telescope group in South Africa. This board will be the common platform for digital-backend development to meet the specific needs of both NRAO and Haystack. Haystack will design a polyphase-filter-bank (PFB) version of the FPGA code to process two 1 GHz-wide IFs into an 8 Gbps Ethernet packet stream compatible with the Mark 5C data system. NRAO, on the other hand, is planning to emulate several VLBA BBCs on a ROACH board (dubbed VDBE), which will also produce a Mark 5C-compatible Ethernet data stream. The hardware for both the Haystack and NRAO systems will be identical; only the FPGA code will be different, allowing the same hardware to adopt the personality of either DBE2 or VDBE.

The first prototype DBE2/VDBE systems are expected to be available for testing in mid-2009.

3. VLBI2010

The major innovation of the VLBI2010 concept is the use of relatively small and fast-slewing antennas (≤12 m) with a receiver spanning a very wide bandwidth (∼2-15 GHz). Observing will utilize four 0.5 to 1 GHz-wide bands spread across the 2-15 GHz receiver capability in order to resolve the more accurate phase delay. This concept has come to be known as the *broadband delay* system.

Haystack Observatory has been working with NASA/GSFC to develop a demonstration system for the broadband delay concept. The basic system was described in the previous Annual Report [1]. In 2007 the first VLBI2010 system was constructed and installed on the 5 m MV-3 antenna at GGAO. Fringes were obtained at X-band between MV-3 and the Westford 18 m antenna. At Westford the standard geodetic S/X circularly polarized feed and receiver were used but with the VLBI2010 backend and recorders. This demonstrated the functionality of the component design.

In 2008 the second VLBI2010 system was completed. It was installed on the Westford antenna for several periods of about two weeks each. Only these periods were available since the Dewar, containing the feed and Low Noise Amplifiers (LNAs), replaces the standard geodetic S/X feed and receiver, and Westford is still used operationally for the IVS geodetic program.

Several improvements were made in 2008.

- To mitigate the interference from digital TV signals near 500 MHz that were saturating the LNAs, filters that pass only frequencies greater than about 3 GHz were installed in the Dewars. Higher quality filters that allow the use of S-band will be incorporated later. To provide additional protection, overload diodes have been installed on all of the LNAs.
- Optical fibers were installed to bring the RF down from the Dewar to the control room. All back-end components were mounted in a single rack (Figure 1).
- Phase calibration has been implemented using geodetic units modified to generate 5 MHz rail spacing. While for early testing the phase cal signal was injected from a probe mounted on the face of the Dewar, the performance improved when the signal was injected via directional

Figure 1. Rack containing a complete VLBI2010 8 gigabit per second data acquisition system. The center chassis contains the optical fiber receivers, splitters, and amplifiers. The four adjacent (silver) chassis with red LED panels are the UpDown Converters. The four black chassis are the Mark 5B+ recorders. The top and bottom chassis are the Digital Back Ends. Each DBE chassis contains two DBE units.

coupler inside the Dewar.

- A digital phase cal generator has been developed and tested but not installed. See Mark 5 memos 56, 59, 60, and 70. This development was necessary because the tunnel diode that provides the pulse in the older phase cal generator is no longer available.
- Software control of the UpDown Converters (UDC) was implemented. This allows the use of a frequency offset to move the phase cal tones off of even-MHz as seen by the Digital Back End (DBE), and it reduces contamination of the phase cal by spurious signals.
- Many scripts were created to simplify the observing procedures since, for each of the four UDCs, DBEs, and Mark 5B+s, some amount of monitoring and control must be incorporated.

After the focus setting at Westford was optimized at 4 GHz, observations were attempted over the frequency range 3.4 GHz to 10 GHz. However, it appears that the optimum setting for 4 GHz is out of focus for the higher frequencies, and fringes were found only below 7 GHz. Subsequently at MV-3, satellite signals at 4, 8, and 11 GHz were used to try to optimize the focus, but the sensitivity did not vary significantly over the available range of focus motion. This is thought to be due to the non-matching subreflector shape for the paraboloidal primary surface.

4. e-VLBI Development

Haystack Observatory continues to support e-VLBI development for VLBI data transfers:

- *Upgrade of 10GigE connection to Haystack:* A 10 Gigabit network connection from Washington, D.C., to Haystack over the Bossnet network was inaugurated in 2007 in cooperation with MIT Lincoln Laboratory, and it is currently being upgraded with new equipment. This link is important for e-VLBI data transfers to Haystack and for the broadband system demonstrations utilizing the Westford 18 m and the MV-3 5 m antennas.

- *Real-time e-VLBI processing of Mark 5B data:* Work to support real-time e-VLBI using Mark 5B on the Mark IV correlator is nearly complete.
- *New connections:* Haystack has been very active in helping to specify, support, and test new e-VLBI connections. New connections to the USNO correlator and to the Kokee, Hawaii site are expected to be completed soon. Testing has begun on the new connection to Fortaleza.

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References

[1] Whitney, A. Technology Development Coordinator, In: International VLBI Service for Geodesy and Astrometry, 2007 Annual Report, NASA/TP-2008-214162, D. Behrend and K. D. Baver, (eds.), 26-29, 2008.